JEMARO

Erasmus Mundus Joint Master Degrees

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STUDENT HANDBOOK

ERASMUS MUNDUS JOINT MASTER DEGREES

Japan-Europe Master on Advanced Robotics: JEMARO

CENTRALE NANTES	**ECOLE CENTRALE DE NANTES**
Keio University	**KEIO UNIVERSITY**
UNIVERSITÀ DEGLI STUDI DI GENOVA	**UNIVERSITY OF GENOA**
POLITECHNIKA WARSZAWSKA WARSAW UNIVERSITY OF TECHNOLOGY	**WARSAW UNIVERSITY OF TECHNOLOGY**

Welcome!

Dear student, welcome to the the Eramus Mundus Master's JEMARO. The purpose of this handbook is to explain how JEMARO works, and what you can expect from it. The information is intended to help you find your feet and settle into postgraduate life as quickly as possible.

The handbook outlines what you can expect at each stage of your studies, the resources available, the structure and staffing within the members institutions, and procedures for dealing with any problems you may encounter.

Please read this handbook carefully as it is in your interest to familiarise yourself with the regulations and procedures. Students who are uncertain about the information in this handbook should get in touch with their course coordinator. We hope you will find your time as a member of the postgraduate community rewarding and enjoyable.

Table of contents

1. JEMARO AT A GLANCE

The Japan-Europe Master on Advanced Robotics (JEMARO) is a 2-year integrated programme (120 ECTS or 30 Japanese Credits) between all the members of the consortium and its goal is to allow students to better understand different perspectives in Robotics and Artificial Intelligence (related to both academia and industry) across Europe (France, Italy and Poland) and Japan. This will be achieved by developing common strategies for knowledge sharing and for enforcing the quality of education in Advanced Robotics.

1.1. Partner institutions & industries

The JEMARO consortium has been jointly designed, and is implemented and fully supported, by 4 major Higher Education Institutions in Japan and Europe awarding master's degrees: Ecole Centrale de Nantes - ECN (France), Keio University - Keio (Japan), University of Genoa - UNIGE (Italy) and Warsaw University of Technology – WUT (Poland).

2 HEIs as Associated Partners, that will be involved in lectures, students' internships, PhD program and strategy committee: Jaume I University (Spain) and Shanghai Jiao Tong University (China).

Besides the student employability target, the JEMARO consortium also offers an innovative educational approach through the involvement of teaching staff coming from 8 industrial partners across Europe and Japan**:** YASKAWA, Soft Servo Systems, NTT Data, Motion Lib, Inc., BA Systems, PIAP-Space, PIAP, IRT Jules Verne.

1.2. Duration and mobility

The programme of study lasts two academic years (120 ECTS or 30 Japanese Credits) with the first year in Europe (ECN, UNIGE or WUT) and the second in Japan (Keio University). The mobility path together with the credits' objectives are presented in Figure 1.

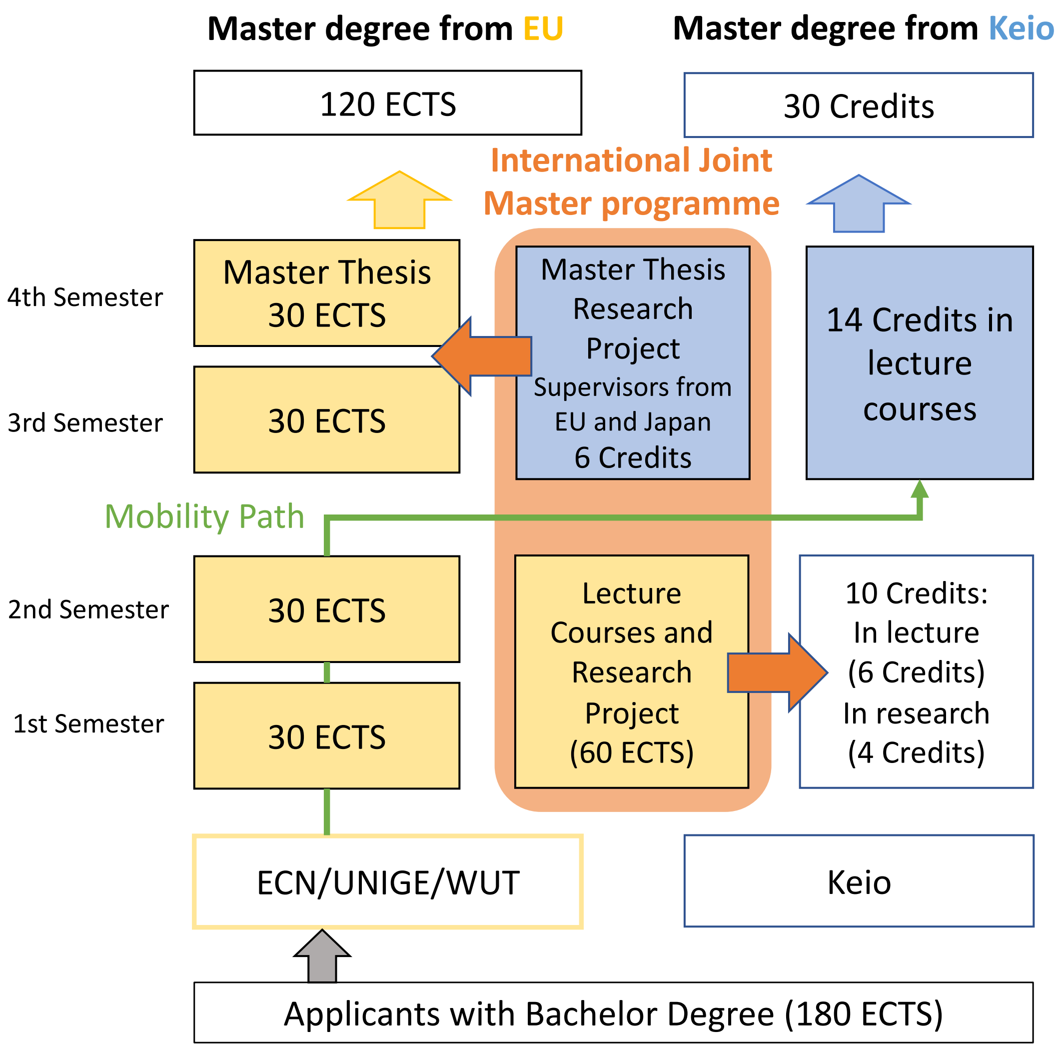

Figure 1: Student mobility path during the 2 years of the master

1.3. Summary of study programme

Before starting the JEMARO Master Programme, students will have to choose their Research Topic they will work on for the 2 years within the so-called Research Track. Their research will be jointly supervised by a European and a Japanese professor over the 2-year programme. When applying, students are asked to rank their 3 chosen Research Topics (control-mechatronics, robotics-human interface and signal processing-biological information) according to their preferences (developed in the cover letter) together with a ranking of the corresponding Keio co-supervisor. For details, see list of Keio Professors and Research Topics here (page down to the staff section).

The aim of the first two semesters of JEMARO is to provide the students with a solid interdisciplinary background across the main areas of robotics (Mathematical Modeling, Control Engineering, Computer Engineering, Mechanical Design and Artificial Intelligence). During these two semesters,

students will also conduct their own research within their Research Topic through bibliographical studies and short-term projects.
For the second year, all JEMARO students will move at Keio in Japan. During the third semester, students will follow courses related to Control, Mechatronics, Robotics, Human Interface, Signal Processing and Biological Information. The fourth semester is set aside for the Master's Thesis. Students carry out their research work under the joint supervision of two advisors from Europe and from Japan.
The language of instruction in JEMARO is English, but local language and culture courses of the hosting countries are included in the programme of study.

1.4. Degrees awarded

Students that graduate from the JEMARO masters' courses will obtain two masters degrees from the institutions where they studied the first and third semesters. The obtained degrees are officially recognised and give full access to PhD study programmes.
The Consortium will deliver Diploma supplement describing the nature, level, context, content and status of the studies that were pursued and successfully completed by the student.

1.5. Admission requirements

The Masters course applies to European and third country-students who already hold a first university degree with 180 ECTS, after at least three years of university studies (at the level of bachelor of science), in a field related to Robotics, such as: Automatic control, mechatronics, computer science, electrical engineering, mechanical engineering, and applied mathematics. The applicants have to be fluent in writing and reading in English (TOEFL (score 220 CBT, 550 PBT, 80 IBT), Cambridge Advanced English Test (score B or higher), IELTS (score 6.5 or higher), TOEIC (800).
The admission is decided on the basis of excellence of the academic records of the student, the quality of her/his former studies, motivations, reference letters and general skills for foreign languages

2. CALENDAR

Each institution will provide to students a precise calendar key dates with dates of exams, holidays, etc. But usually, the first and third semester start on September and finish on January/February. The second and fourth semester start on February/March and finish on June/July.

3. STRUCTURE OF THE FIRST YEAR PROGRAMME IN EUROPE

3.1. Introduction

The aim of the first year is to provide the students a solid interdisciplinary background across the main areas of robotics: perception (computer vision, sensors, signal processing), cognition (computer science, artificial intelligence, human computer interaction), action (kinematics, dynamics, control), and mathematical foundation (modelling, simulation, optimization).

The structure of the first year, M1, is shown in Table 1. It consists of two semesters, S1 (from September until January/February) and S2 (from February/March until June/July). The first semester starts with eight days of intensive local language course. The objectives, contents, assessments, etc. of all the modules are described in Annex 1.

Table 1: Structure of the first year (M1)

First 8 days (September)	First semester (30 ECTS)	Second semester (30 ECTS)
- Local language course	- Interdisciplinary background modules - Local language course	- Interdisciplinary background Modules - (Optional) Local language course*

* Local language will be offered optionally without ECTS.

3.2. Fall Semester Courses

The student will select several modules to obtain 30 ECTS (the number of credits can be different from one institution to the other). Some modules like the first semester language course are compulsory. This is mentioned in the course syllabus of Annex 1.

At Centrale Nantes (France):

Courses	Lead Professors	ECTS
Signal Processing	E. LE CARPENTIER	5
Classical Linear Control (compulsory)	G. LEBRET	5
Artificial Intelligence (compulsory)	D. LIME	4
Modelling of Manipulators (compulsory)	O. KERMORGANT	4
Advanced and Robot Programming	G. GARCIA	4
Embedded Computing	M. BRIDAY	4

Mechanical Design Methods in Robotics	S. CARO	4
Modern Languages* (compulsory)	Language Department at ECN	4

*French as Foreign Language

At University of Genoa (Italy):

Courses	Lead Professors	ECTS
Software Architecture for Robotics (compulsory)	F. MASTROGIOVANNI	5
Real-time Operating Systems	A. SGORBISSA	5
Advanced and Robot Programming	R. ZACCARIA	5
Modelling and Control of Manipulators (compulsory)	G. CASALINO	6
Control of Linear Multivariable Systems (compulsory)	G. CANNATA	5
Mechanics of Mechanisms and Machines	Z. DIMITER	5
Optimization Techniques	M. SANGUINETI	5
Modern Languages* (compulsory)	Language Department at UNIGE	5

*Italian as Foreign Language

At Warsaw University of Technology (Poland), all courses are compulsory:

Courses	Lead Professors	ECTS
Signal Processing	W. KRASPRZAK	5
Real-time Systems	T. KRUK	5
Modelling and Control of Manipulators	C. ZIELINSKI	6
Computer Vision	W. KRASPRZAK	5
Neural Networks	A. KORDECKI	5
Modern Languages*	Language Department at WUT	4

*Polish as Foreign Language

3.3. Spring Semester Courses

The student will select several modules to obtain 30 ECTS (the number of credits can be different from one institution to the other. Some modules are compulsory, and some have prerequisites courses from the first semester. This is mentioned in the course syllabus of Annex 1.

At Centrale Nantes (France), all courses are compulsory:

Courses	Lead Professors	ECTS
Group Project	G. LEBRET	6
Optimization Techniques	F. BENNIS	4
Mobile Robots	G. GARCIA	4
Dynamic Model Based Control	S. BRIOT/G. LEBRET	4
Programming Real-time Systems	S. FAUCOU	4

Software Architecture for Robotics	G. GARCIA	4
Computer Vision	V. FREMONT	4
Modern Languages* (Optional)	Language Department at ECN	4

*French as Foreign Language

At University of Genoa (Italy):

Courses	Lead Professors	ECTS
Group Project (compulsory)	Professors at UNIGE	5
Computer Vision (compulsory)	N. NOCETI / F. SOLARI	5
Human-Computer Interaction	A. CAMURRI	5
Artificial Intelligence (compulsory)	A. TACCHELLA/ E. GIUNCHIGLIA	5
Mobile Robots	G. GARCIA	5
Non-Linear Control Techniques	C. MOOG	5
Mechanical Design Methods in Robotics (compulsory)	M. ZOPPI	5
Modern Languages* (Optional)	Language Department at UNIGE	5

*Italian as Foreign Language

At Warsaw University of Technology (Poland), all courses are compulsory:

Courses	Lead Professors	ECTS
Group Project	Professors at WUT	5
Mechanical Design Methods in Robotics	K. MIANOWSKI	5
Robot Programming Methods	C. ZIELINSKI	4
Mobile Robots	W. SZYNKIEWICZ	4
Artificial Intelligence	W. KRASPRZAK	4
Embedded Systems	T. ZIELINSKA	4
Optimization Techniques	W. OGRYCZAK	4
Modern Languages* (Optional)	Language Department at WUT	4

*Polish as Foreign Language

4. STRUCTURE OF THE SECOND YEAR PROGRAMME IN JAPAN

4.1. Introduction

For the whole second year of the master's programme, all students will move to Keio University in Japan.
Locally, the programme will be split between courses related to control, mechatronics, robotics, human interface, signal processing and biological information, and research activities conducted under the joint supervision of professors from EU institutions and from Keio. Students will devote time to the Research Track to conduct their own research and to earn Japanese Research Credits. For the second year, the Research Track will end with the Master's Thesis Defense. Local partner companies could also be involved in the courses and in the thesis supervision. The Research Topic and the Japanese supervisor are the one selected on the application website before starting the Master programme. As mentioned previously, for details, see the list of Keio Professors and Research Topics here (page down to the staff section).

Examples of courses available at Keio and linked to robotics are shown in the table below. The full list of courses offered in English are proposed in Annex 2. Each course gives two (2) Lecture Credits so students have to take 7 courses. The full syllabus is available here. Compulsory Japanese language course is handles through the courses entitled "science and technology in Japanese culture".

Examples of courses proposed at KEIO	
Ultraprecision Machining and Metrology	MEMS: Design and Fabrication
Advance Course for Actuator Engineering	Space Exploration Engineering
Digital Wireless Communications	Computer Vision
Mixed Reality	Advanced Control Systems Design
Intelligent Machine System	Ad Hoc & Sensor Network
Design of Physically Grounded Communication System	Computational Structural Mechanics
Applied system design engineering	Medical Image Processing
Electromechanial Integration System	Control Engineering
Robust Control Theory	Advanced System Electronics
Science and Technology in Japanese Culture (compulsory)	

Disclaimer

The Consortium has made all reasonable efforts to ensure that the information contained within this publication is accurate and up-to-date when published but can accept no responsibility for any errors or omissions.

The Consortium reserves the right to revise, alter or discontinue modules and to amend regulations and procedures at any time, but every effort will be made to notify interested parties.

It should be noted that not every module listed in this handbook may be available every year, and changes may be made to the details of the modules.

5. ANNEX 1: SYLLABUS OF THE FIRST YEAR MODULES IN EUROPE

5.1. Syllabus of courses offered in Centrale Nantes

Signal Processing			
Credits: 5 **Fall Semester** **Compulsory: No**			
Format	Lectures: 14h	Lab: 18h	
Lecturer: Eric LE CARPENTIER			

Objectives:

- To interpret the spectral representations of signals
- To understand the time sampling of signals (sample rate, anti-aliasing filter etc.)
- To model a system using the transfer functions language
- To model a system using the state space language
- To switch from one representation to the other
- To link the physical phenomena to the parameters of these representations (stability, response velocity etc.)
- To simulate these mathematical representations with adapted scientific software tools (Matlab, Simulink).

Contents:

- Analysis of continuous-time and discrete-time signals
- Modelling of continuous-time and discrete-time linear time invariant (LTI) systems
- Design of an actual digital control implementation
- Lab work

Assessment: 30% continuous assessment, 70% final exam

Recommended texts and further readings:

- Modern Signals and Systems, H. Kwakernaak, R. Sivan, Prentice Hall.
- Signals and Systems, R. Baraniuk, http://www.eng.ucy.ac.cy/cpitris/courses/ece623/notes/SignalsAndSystems.pdf
- Signal processing. Introduction to signals and systems theory, E. Le Carpentier, https://hippocampus.ec-nantes.fr/mod/resource/view.php?id=9179

Classical Linear Control			
Credits: 5 **Fall Semester** **Compulsory: Yes**			
Format	Lectures: 22h	Lab: 4h	Tutorials: 6h
Lecturer: Guy LEBRET			

Objectives:

- To be able to analyse the dynamic behaviour of a SISO linear system
- To be able to design a PID type controller as an example of a feedback controller
- To be able to design a feedforward controller to increase tracking performance

Contents:

- Description of SISO linear systems through the transfer function
- Analysis of behaviour (poles/zeros, first/second/more general systems, time domain/frequency domain responses etc)

• Definition the Control objectives (stability/performance, tracking/regulation) • Nominal/robust stability (Routh, Nyquist criteria, stability margins). • Nominal/robust performance and the unavoidable trades off between stability and performance. • Synthesis of PID type controllers, using frequency approach tunings, in a classical closed loop (one degree of freedom controller strategy). • Possibility of introducing a feedforward contribution which tries to “invert” the first closed loop obtained (two degrees of freedom controllers).
Assessment: 30% continuous assessment, 70% final exam
Recommended texts and further readings: • Modern Control Systems, R.C. Dorf and R.H. Bishop, Prentice Hall, 2011. • Control Systems Engineering, N. S. Nise, John Wiley & Sons, 2011. • Control system design, G.C. Goodwin, S.F. Graebe and M.E. Salgado, Prentice Hall, 2001. • Multivariable Feedback Control Analysis and Design, D.S. Skogestad and I. Postlethwaite, Wiley, 2005.

Artificial Intelligence			
Credits: 4	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 16h	Lab: 12h	Tutorials: 4h
Lecturer: Didier LIME			
Objectives: • To be able to use and implement graph-based strategy search, in particular using Markov decision Processes • To be able to use and implement decision tree and artificial neural network learning (including the basics of deep learning) • To be able to use and implement several simple flavors of reinforcement learning. **Contents:** • Basic path-finding • Account for non-determinism • Probabilistic outcomes • Partial observability • Specific problems of supervised learning and reinforcement learning			
Assessment: 100% final exam			
Recommended texts and further readings: • S. Russel, P. Norvig. Artificial Intelligence: A Modern Approach (3rd ed). Pearson, 2009.			

Modelling of manipulators			
Credits: 4	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 16h	Lab: 16h	
Lecturer: Olivier Kermorgant			
Objectives: • To have a clear view of 3D geometry, including rotation parametrization and velocity screws • To define a table of modified Denavit-Hartenberg parameters to model a robot from a			

sketch

- To compute (manually or with software) the direct and differential kinematic models
- To derive the inverse kinematic model for standard manipulators (6R / 3P3R)
- To understand position and velocity control modes
- To know how to generate a trajectory from a sequence of 3D waypoints
- To know various symbolic or numeric software tools that can be used to model and control Robots

Contents:

- Robot architecture, joint and operational spaces
- Homogeneous transformation matrices, 3D geometry, velocity screw
- Modified Denavit-Hartenberg parametrization and direct kinematics
- Definition and computation of the robot Jacobian
- Inverse kinematics in exact and iterative forms
- Trajectory generation
- Basic position and velocity control modes (trajectory / velocity tracking)

Assessment: 100% final exam

Recommended texts and further readings:

- Slides and labs are available online.
- W. Khalil, and E. Dombre, Modeling, identification and control of robots, Hermes Penton, 2002.
- C. Canudas, B. Siciliano, G. Bastin (editors), Theory of Robot Control, Springer-Verlag, 1996•
- J. Angeles, Fundamentals of Robotic Mechanical Systems, Springer-Verlag, New York, 2002.

Embedded Computing			
Credits: 4	**Fall Semester**	**Compulsory: No**	
Format	Lectures: 12h	Lab: 16h	Tutorials: 4h
Lecturer: Mikael BRIDAY			

Objectives:

- Understand the architecture of a microcontroller;
- Design a low-level driver to access a peripheral of a microcontroller and deal with microcontroller interrupts;
- Design a bare metal application.

Contents:

The first part of the course deals with the software environment for deeply embedded systems:

- Cross compiler: bit operations, memory model, common C design rules, low level C and assembly specific attributes
- Link script to declare the memory model to the application
- Debugging with a JTAG probe (breakpoints, memory watch, etc)

The second part introduces hardware peripherals of a microcontroller to interact with the environment:

- Standard GPIO
- Timers
- Serial communication peripherals

- Interrupts

The third part of the module focuses on the design of a bare metal application, including concurrent execution of both software and hardware parts.

Assessment: 100% final exam (2h)

Recommended texts and further readings:

- Philip Koopman, Better Embedded Software Systems, Drumnadrochit Education LLC, 2010
- D. Patterson & J. Hennessy, Computer Organization and Design – ARM Edition, Morgan Kaufmann, 2017

Mechanical Design Methods in Robotics

Credits: 4 **Fall Semester** **Compulsory: No**

Format	Lectures: 20h	Lab: 12h	

Lecturer: Stéphane CARO

Objectives:

- To design serial and parallel robotic manipulators.
- To correctly formulate the information required for conceptual design (requirements),
- To use CAD systems on the basic level for the design of a typical mechanism (serial arm),
- To elaborate the design on general level without consideration of material, drive systems and actuators,
- To generate manufacturing drawings.

Contents:

- Conceptual design: concept generation, concept evaluation.
- Product design: documentation, product generation, evaluation for function and performance, evaluation for cost, ease of assembly and other measures.
- Computer aided design, use of CAD software.
- The design of robotic production cells.
- Fundamentals of integrated design of control and drive systems taking into account measurement, gearing and transmission systems.

Assessment: Final exam and final project

Recommended texts and further readings:

- French, M. J. Conceptual Design for Engineers, 3rd ed., 1999 (Springer)
- Pahl, G. and Beitz, W. Engineering Design: A Systematic Approach, 2nd ed. Wallace, K.M.
- (editor); Blessing, L., Bauert, F. and Wallace, K.M. (translators), 1996 (Springer-Verlag, London)
- Suh, N.P. The Principles of Design, 1990 (Oxford University Press, Oxford)
- Suh, N.P. Axiomatic Design. Advances and Applications, 2001 (Oxford University Press, Oxford)
- Kong X. and Gosselin, C., Type Synthesis of Parallel Mechanisms, Springer Tracts in Advanced Robotics, 2007.

Advanced and Robot Programming

Credits: 4 **Fall Semester** **Compulsory: Yes**

Format	Lectures: 8h	Lab: 24h	

Lecturer: Gaëtan GARCIA / Olivier KERMORGANT

Objectives:

To give the students the fundamentals of:

- Modern programming (with C++)
- Industrial robot manipulator programming with specialized robot languages

Contents:

C++:

- Basic types, STL useful classes (string, vector, pair, map), struct
- Control blocks: if/then/else, for, while, switch
- Functions: argument passing, overloading
- Classes: attributes and methods, inheritance
- Templates, lambda-functions and STL algorithms
- Code organization
- Compilation with Cmake, using external libraries
- Debugger and profiler

Industrial manipulator programming:

- The different levels of programming,
- Tools for teaching locations,
- Robots, sensors and flexibility,
- Synchronous vs asynchronous motions, guarded motions,
- Tool-level programming,
- Real-time aspects of robot programming,
- The V+ language, including its real-time aspects and sensor-handling capabilities.

Assessment: continuous assessment 50%, final exam 50%

Recommended texts and further readings:

- C. Blume, W. Jakob, Programming Languages for Industrial Robots, Springer Verlag.
- Stäubli: RX Robots Technical Documentation, 2001.
- Bruce Eckel, Thinking in C++, volumes 1 and 2, 2007.

Group project			
Credits: 6	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 0h	Lab: 0h	Project: 32h

Lecturer: Guy LEBRET and professors at ECN

Objectives:

- To contribute to solving a scientific, technological or theoretical problem proposed by any of the instructors of the master (professors, assistant professors, researchers etc.) or industrial partners.

Contents:

- The students (individually or often a group of two) organize the project. Depending on the subject, a bibliography may be necessary, an original methodology or solution can be proposed or it can involve purely the application of techniques learned throughout the courses.
- 32 hours are set aside for the project in the timetable, but additional personal work will be required. Project assessment is based on a written report and an oral presentation.

Assessment: written report and oral presentation (100%)

Recommended texts and further readings:
• Relevant material will be given by the teacher during lectures.

Optimization techniques			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 16h	Lab: 16h	
Lecturer: Fouad BENNIS			
Objectives: • To acquire the ability to formalise, select the appropriate method, implement the optimisation problem and then analyse the results in order to take the best decision regarding the objectives, variables and constraints **Contents:** • Basic concepts of optimization, • Gradient based methods, • Evolutionary algorithms, • Multi objective optimization methods, • Robust optimization methods, • Multidisciplinary optimization problems, • Programming aspects, • Use of optimization toolbox			
Assessment: continuous assessment 50%, final exam 50%			
Recommended texts and further readings: • R. Fletcher, Practical Methods of Optimization, Wiley, 2000. • Mitchell Melanie: An Introduction to Genetic Algorithms, MIT Press 1996			

Mobile Robots			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 20h	Lab: 12h	
Lecturer: Gaëtan GARCIA			
Objectives: • To provide students with the necessary tools to model, localize and control conventional wheeled mobile robot **Contents:** • Modelling of wheeled Robots: Constraint equations, Classification of robots using degrees of mobility and steerability, Posture kinematic model, Configuration kinematic model, Motorisation of wheels. • Localization: Relative localization using odometry, Absolute localisation, Localization sensors, Localization using extended Kalman filtering. • Control: Controllability and stabilization, static and dynamic feedback linearization, nonlinear control based on Lyapunov functions. • Practical Work: The students will study various control laws in simulation. They will also implement a Kalman filter-based localization algorithm using data recorded with a real			

robot.
Assessment: continuous assessment 30%, final exam 70%
Recommended texts and further readings: • "Theory of robot control", Carlos Canudas de Wit, Bruno Siciliano, Georges Bastin, Springer Science & Business Media, 2012 - 392 pages. • PDF documents provided by the teachers.

Dynamic Model Based Control			
Credits: 4 **Spring Semester** **Compulsory: Yes**			
Format	Lectures: 22h	Lab: 4h	Tutorials: 6h
Lecturer: Sébastien BRIOT / Guy LEBRET			
Objectives: • To present a unified methodology to obtain control laws. • To explore different formalisms for the computation of the dynamic model will be explored (Newton-Euler, Lagrange equations). **Contents:** • State space approach of linear multivariable systems (Time domain state response, modal decomposition of the response, controllability, observability…) • Mechanisms or more specifically, serial robots (tecalls of classical mechanics, Newton-Euler equations, Euler-Lagrange equations, optimal computation of dynamic models for serial robots)			
Assessment: continuous assessment 30%, final exam 70%			
Recommended texts and further readings: • "Control system design", G.C. Goodwin, S.F. Graebe and M.E. Salgado, Prentice Hall, 2001. Page 21 of 24 • "Linear Multivariable Control, A Geometric Approach", W.M.Wonham. Springer Verlag, New York, 1985. "Linear Systems", T. Kailath, Prentice-Hall, New Jersey, 1980. • "Modelling, Identification and Control of Robots" W. Khalil and E. Dombre, Hermes Penton, Ltd, 2002			

Programming Real-time Systems			
Credits: 4 **Spring Semester** **Compulsory: Yes**			
Format	Lectures: 12h	Lab: 16h	Tutorials: 4h
Lecturer: Sébastien FAUCOU			
Objectives: At the end of the course the students will be able to: • Design the software architecture of a real-time system • Build deterministic programmes with a multitasking RTOS • Handle time and recurring events in a real-time application • Understand and solve race conditions in concurrent software **Contents:** • Introduction to real time systems: what is a real time system, classes of timing constraints, basic model and results on real time scheduling • Trampoline RTOS: what is a RTOS, when is it useful, architecture of Trampoline, build			

process, task management and scheduling, synchronisation, handling of recurring events, shared resources • Design of real time applications: case studies and design patterns	
Assessment: continuous assessment 30%, final exam 70%	
Recommended texts and further readings: • Alan Burns, Andy Wellings, Analysable Real-Time Systems: Programmed in Ada, CreateSpace Independent Publishing Platform, 2016 • Giorgio C. Buttazzo, Hard Real-Time Computing Systems: Predictable Scheduling Algorithms and Applications, Springer, 2011 • Philip Koopman, Better Embedded Software Systems, Drumnadrochit Education LLC, 2010	
Prerequisites: Embedded Computing course from S1	

Software Architecture for Robotics			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 12h	Lab: 20h	
Lecturer: Gaëtan GARCIA			
Objectives: • To define which sensory information is needed and how it must be processed; • To couple sensory information and internal representation structures, which must be appropriate in terms of efficiency, computational load and usability; • To design and develop algorithms to operate on such representation structures; • To embed those algorithms in software modules and components, which must be concurrently executed on (typically real-time) operating systems. **Contents:** • Design patterns for robot software development, • Component-based software engineering aspects, • Typologies of software architecture for robots, and their use in real-world scenarios, • Biologically-inspired approaches to robot software design, • Real-time and non-real-time software components, • Integration of robot perception, knowledge representation, reasoning, and action. • Practical introduction to ROS in the labs.			
Assessment: continuous assessment 50%, final exam 50%			
Recommended texts and further readings: • Relevant material will be given by the teacher during lectures.			

Computer Vision			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 20h	Lab: 12h	
Lecturer: Vincent FREMONT			
Objectives: • To acquire knowledge and skills in computer vision and image processing to understand and to master methods for artificial perception and scene understanding.			

• To learn to implement current visual odometry pipelines used in mobile robots and to understand the basic principles of Deep Learning algorithms for robotic applications. **Contents:** • Introduction • Image Formation 1: perspective projection and camera models • Image Formation 2: camera calibration algorithms • Filtering and Edge detection • Feature Point Detection • Multiple-view Geometry and Robust Estimation • Optical Flow and Feature Tracking • Visual SLAM Frameworks • Deep Learning for robotics and Semantic Segmentation
Assessment: Lab assessment 50%, final exam 50%
Recommended texts and further readings: Recommended textbooks: • Digital Image Processing, by Rafael C. Gonzalez and Richard E. Woods, 2018 • Computer Vision: Algorithms and Applications, by Richard Szeliski, 2009. • Multiple view Geometry, by R. Hartley and A. Zisserman, 2003. • An Invitation to 3D Vision, by Y. Ma, S. Soatto, J. Kosecka, S.S. Sastry, 2004. • Robotics, Vision and Control: Fundamental Algorithms, by Peter Corke, 2011. Online courses: • Course by Davide Scaramuzza: http://rpg.ifi.uzh.ch/teaching.html • Course by James Hays at Brown University: https://www.cc.gatech.edu/~hays/ • Course by Andrea Vedaldi: http://www.robots.ox.ac.uk/~vedaldi/teach.html

5.2. Syllabus of the courses offered at University of Genoa

<table>
<tr><th colspan="4">Software Architecture for Robotics</th></tr>
<tr><td colspan="4">Credits: 5   Fall Semester   Compulsory: Yes</td></tr>
<tr><td>Format</td><td>Lectures: 14h</td><td>Lab: 18h</td><td></td></tr>
<tr><td colspan="4">Lecturer: Fulvio MASTROGIOVANNI</td></tr>
<tr><td colspan="4">Objectives:
• To define which sensor information is needed and how it must be processed;
• To couple sensor information and internal representation structures, which are appropriate in terms of efficiency, computational load, and usability;
• To design and develop algorithms to operate on such representation structures;
• To embed those algorithms in software modules and components, which must concurrently be executed on (typically real-time) operating systems

Contents:
• The robot software design process: requirements and challenges
• The component-based software engineering (CBSE) methodology:
• Bio-inspired approaches to the development of software architectures for robots:
• Knowledge representation and reasoning:</td></tr>
<tr><td colspan="4">Assessment: 100% continuous assessment (several group assignments)</td></tr>
<tr><td colspan="4">Recommended texts and further readings:
• Relevant material will be given by the teacher during lectures.</td></tr>
</table>

<table>
<tr><th colspan="4">Real-time Operating Systems</th></tr>
<tr><td colspan="4">Credits: 5   Fall Semester   Compulsory: Yes</td></tr>
<tr><td>Format</td><td>Lectures: 14h</td><td>Lab: 18h</td><td></td></tr>
<tr><td colspan="4">Lecturer: Antonio SGORBISSA</td></tr>
<tr><td colspan="4">Objectives:
• To understand problems related to real-time applications and operating systems;
• To understand how to use real-time operating systems following the Posix standard and Linux-RTAI
• To expand the acquired knowledge to understand how to use additional real-time operating systems that have not been presented in the class;
• To apply the acquired knowledge to solve problems, in particular for the design of real-time applications;
• To analyse the characteristics of state-of-the-art real-time operating systems and categorize them on the basis of such characteristics.
•
Contents:
• Real-time operating systems
• Soft real-time systems (Posix)
• Linux Device Drivers</td></tr>
</table>

- Hard real-time systems

Assessment: 100% final exam

Recommended texts and further readings:

- Buttazzo, Giorgio C. Hard Real-time Computing Systems, Kluwer Academic publishers, 1997
- Alessandro Rubini and Jonathan Corbet, Linux Device Drivers, Third Edition, O'Reilly and Associates, June, 2001 (available online at http://oreilly.com/openbook/linuxdrive3/book/)
- Tom Wagner and Don Towsley, Getting Started With POSIX Threads (available online)
- https://www.rtai.org/

Advanced and Robot Programming			
Credits: 5 Fall Semester Compulsory: No			
Format	Lectures: 14h	Lab: 18h	
Lecturer: Renato ZACCARIA			

Objectives:

To get the fundamentals of:

- Posix programming
- Concurrent programming
- Interprocess communication
- ROS environment
- ROS programming

Contents:

- Distributed programming
- Real time features
- POSIX programming: process, communication, synchronization
- Unix/Linux basic architecture
- ROS

Assessment: 100% final exam

Recommended texts and further readings:

- Relevant material will be given by the teacher during lectures.

Modelling and Control of Manipulators			
Credits: 6 Fall Semester Compulsory: Yes			
Format	Lectures: 14h	Lab: 18h	
Lecturer: Giuseppe CASALINO			

Objectives:

- To master the fundamentals of the modelling and control techniques of serial manipulators.

Contents:

- Robot architectures
- Geometric modelling
- Kinematic modelling
- Dynamic modelling and its applications
- Classical PID controller

• Computed torque controller
Assessment: 30% continuous assessment, 70% final exam
Recommended texts and further readings: • W. Khalil, and E. Dombre, Modeling, identification and control of robots, Hermes Penton, London, 2002. • C.Canudas, B. Siciliano, G.Bastin (editors), Theory of Robot Control, Springer-Verlag, 1996. • J. Angeles, Fundamentals of Robotic Mechanical Systems, Springer-Verlag, New York, 2002.

Control of Linear Multivariable Systems			
Credits: 5	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 14h	Lab: 18h	
Lecturer: Giorgio Cannata			
Objectives: • To tackle control/regulation problems for MIMO linear systems • To apply methods and algorithms to synthesize MIMO (optimal) digital controllers **Contents:** • Methods for the control of multi-input multi-output (MIMO) linear time invariant systems arising in many engineering applications including: robotics, mechatronics, process control, avionics, self-driving vehicles, bio-medical systems, etc. • Methods for the optimal control of multi-variable (linear) dynamic systems			
Assessment: 30% continuous assessment, 70% final exam			
Recommended texts and further readings: • Relevant material will be given by the teacher during lectures.			

Mechanics of Mechanisms and Machines			
Credits: 5	**Fall Semester**	**Compulsory: No**	
Format	Lectures: 14h	Lab: 18h	
Lecturer: Dimiter ZLATANOV			
Objectives: The course will introduce students to modern mathematical methods of modelling rigid-body motion as applied to the study, design, and control of robotic mechanisms. The focus will be on the geometry, kinematics, and statics of articulated multi-body systems, with targeted applications in mechanism analysis and synthesis, as well as robot dynamics, flexibility, and control. **Contents:** • Linear spaces, screws, twists, and wrenches: the basics of screw theory. • Application: constraint analysis and synthesis of parallel manipulators. • Kinematic geometry of planar mechanisms. • Velocity and singularity analysis. • Statics of mechanisms. • Acceleration in rigid-body systems, introduction to dynamics.			
Assessment: 50% continuous assessment, 50% final exam			
Recommended texts and further readings:			

• Hunt, K., 1978, Kinematic geometry of mechanisms, Clarendon Press. • Murray, R.M, Li, Z., and Sastry, S.S., 1994, Mathematical introduction to robotic manipulation, CRC. • John Joseph Uicker, J.J., G. R. Pennock, G.R., and Shigley, J.E., 2016, Theory of Machines and Mechanisms. 5th ed. New York: Oxford University Press.

Optimization Techniques			
Credits: 5 **Fall Semester** **Compulsory: No**			
Format	Lectures: 14 h	Lab: 18h	
Lecturer: Marcelo SANGUINETI			
Objectives: • To interpret and shape a decision-making process in terms of an optimization problem • To identify the decision-making variables • To master the cost function to minimize (or the figure of merit to maximize) and the constraints • To frame the problem within the range of problems considered "canonical" • To realize the "matching" between the solving algorithm (to choose from existing or to be designed) and an appropriate processing software support. **Contents:** • Introduction. Optimization and Operations Research for Robotics. Optimization models and methods • Linear programming model and algorithms • Integer linear programming model and algorithms • Nonlinear programming model and algorithms • Graph optimization models and algorithms • N-stage optimization: dynamic programming model and algorithms • Putting things together: models, methods, and algorithms for the optimisation of robotic systems • Software tools for optimization • Case studies from Robotics			
Assessment: 30% continuous assessment, 70% final exam			
Recommended texts and further readings: • Lecture notes provided by the teacher (study material will be available in the official study portal or in the teacher's web page)			

Computer Vision			
Credits: 5 **Spring Semester** **Compulsory: Yes**			
Format	Lectures: 14h	Lab: 18h	
Lecturer: Nicoletta NOCETI / Fabio SOLARI			
Objectives:			

• To be able to understand the main theoretical concepts of computer vision • To be able to design and implement classical computer vision algorithms • To get an overview of the main application domains, with a special reference to the robotics scenario. **Contents:** • Introduction to computer vision for robotics applications • Image processing fundamentals • Motion analysis and navigation • Geometry • Image matching and image retrieval • Introduction to object and action recognition methods in HRI
Assessment: continuous assessment 30%, final exam 70%
Recommended texts and further readings: • R.C. Gonzalez and R.E. Woods, Digital image processing, Prentice-Hall, 2008. • E. Trucco and A. Verri, Introductory Techniques for 3-D Computer Vision, Prentice Hall, 1998.

Human-Computer Interaction			
Credits: 5 **Spring Semester** **Compulsory: No**			
Format	Lectures: 14h	Lab: 18h	
Lecturer: Antonio CAMURRI			
Objectives: Acquisition of concrete skills in the Interaction Design (ID) development process for multimedia and multimodal interfaces: **Contents:** • Introduction to Human Computer Interaction and Interaction Design (ID). The ACM curricula on HCI. • Foundations of human perception and cognition for human-centred interactive systems. Usability and User experience. • Interfaces: command-based, WIMP and GUI, Virtual reality, Mobiles, Multimedia, Speech, Touch, Air-based gesture, Motion Capture, Haptic, Shareable, Tangible, Wearable, AR/MR, Multimodal. • Designing, developing, and evaluating interfaces: the ID development process. • Design Principles – Usability: learnability, visibility, errors, efficiency. • Design Techniques: Task, User, Domain Analysis, Prototyping, User testing; • Theories and models supporting the development process. • Evaluation and research methods: • Experiment design; Controlled experiments; Data analysis • The role of sound in interfaces: Sound and Music Computing • Emotional and Social Interfaces.			
Assessment: practical project 30%, final exam (written & oral) 70%			
Recommended texts and further readings: • Course slides and suggested readings available online from AulaWeb page of the course (MS			

in Ingegneria Informatica);
- Preece, Rogers, Sharp (2015) “Interaction Design – Beyond Human-Computer Interaction”, Wiley, 4th Ed. Slides available online at http://www.id-book.com/slides_index.php

Artificial Intelligence			
Credits: 5	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 14h	Lab: 18h	
Lecturer: Armando TACCHELLA / Enrico GIUNCHIGLIA			
Objectives: • Introduction to Artificial Intelligence • To learn the basics in propositional and first order logic • To apply these basics in the context of knowledge representation and reasoning • To learn basic principles of heuristic search and planning **Contents:** • Knowledge representation formalisms and techniques • Automated reasoning • Informed and uninformed search • Automated planning			
Assessment: Written and oral			
Recommended texts and further readings: • Russell Norvig, "Artificial Intelligence".			

Mobile Robots			
Credits: 5	**Spring Semester**	**Compulsory: No**	
Format	Lectures: 14h	Lab: 18h	
Lecturer: Gaëtan GARCIA			
Objectives: • To provide students with the necessary tools to model, localize and control conventional wheeled mobile robot **Contents:** • Modelling of wheeled Robots: Constraint equations, Classification of robots using degrees of mobility and steerability, Posture kinematic model, Configuration kinematic model, Motorisation of wheels. • Localization: Relative localization using odometry, Absolute localisation, Localization sensors, Localization using extended Kalman filtering. • Control: Controllability and stabilization, static and dynamic feedback linearization, nonlinear control based on Lyapunov functions. • Practical Work: The students will study various control laws in simulation. They will also implement a Kalman filter-based localization algorithm using data recorded with a real robot.			
Assessment: continuous assessment 30%, final exam 70%			
Recommended texts and further readings:			

• "Theory of robot control", Carlos Canudas de Wit, Bruno Siciliano, Georges Bastin, Springer Science & Business Media, 2012 - 392 pages. • PDF documents provided by the teachers.

Non-Linear Control Techniques			
Credits: 5	**Spring Semester**	**Compulsory: No**	
Format	Lectures: 24h	Tutorials: 16h	
Lecturer: Claude MOOG			
Objectives: • Understand the theoretical fundamentals on the control of nonlinear systems, • Apply advanced nonlinear control on a variety of robotics systems, • Implement control strategy and calculate the corresponding observer. **Contents:** • Introduction to the algebraic approach for nonlinear systems and its mathematical tools. • Structural analysis, concepts of relative degree, of controllability and observability. • Control methods: feedback linearization, decoupling, reference trajectory tracking. • Lyapunov functions and their properties. • Recursive global stabilization by state feedback of nonlinear systems. • Design of a nonlinear observer. Special observability forms for input-affine systems. • Observer-based stabilization. Methods to avoid finite-escape time. • Dynamic output feedback semi-global stabilization.			
Assessment: continuous assessment 30%, final exam 70%			
Recommended texts and further readings: • G. Conte, C.H. Moog and A.M. Perdon, *Algebraic Methods for Nonlinear Control Systems.Theory and Applications*, Springer-Verlag, 2006. • Isidori, *Nonlinear Control Systems. 2nd edition*, Springer-Verlag, 1989. • R. Marino and P. Tomei, *Nonlinear Control Design: Geometric, Adaptive and Robust*, Prentice Hall, 1995. • M. Vidyasagar, *Nonlinear Systems Analysis*, Prentice Hall, 1993.			

Mechanical Design methods in Robotics			
Credits: 5	**Spring Semester**	**Compulsory: No**	
Format	Lectures: 14h	Lab: 18h	
Lecturer: Matteo ZOPPI			
Objectives: • To understand the relation between use, function and design starting from simple items and scaling up to robotic systems. • To understand the steps in engineering design of mechanical and mechatronic devices • To get skills in geometric modelling, adding of functional information, run of structural and multibody simulations using SW for computer aided engineering (CREO of PTC is currently adopted) • To develop a design case through the course up to 3D printing and presentation and communication of the process and results.			

Contents:
• Mechanical and mechatronic engineering design • Steps of a design process • Definition of the architecture and analysis wrt task and function • Conceptualization and embodiment • 3D geometric modelling • Functionalization of the model: dynamic and structural information • Run of simulations: method and practice • 3D printing: preparation of models and print; adjustment for assembly
Assessment: continuous assessment 30%, final exam 70%
Recommended texts and further readings: • Relevant material will be given by the teacher during lectures.

Group Project			
Credits: 5	**Spring Semester**	**Compulsory: Yes**	
Format	Project: 32h		
Lecturer: Renato ZACCARIA and professors at UNIGE			
Objectives: The aim of this module is to provide students with the opportunity to apply their specialized knowledge to the solution of a real problem and gain practical experience of the processes involved in the team-based design and testing of a robotic system. Each group, of three students, will define the system to be realized.			
Assessment: 100% Oral and Lab			
Recommended texts and further readings: • Recommended texts will be given by the lecturers.			

5.3. Syllabus of the courses offered at Warsaw University of Technology

Signal Processing			
Credits: 5	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 30h	Tutorials: 15h	
Lecturer: Wlodzimierz KRASPRZAK			

Objectives:

To present the methods of description and transformation of deterministic signals for both continuous and discrete time cases. To present also basic knowledge about random signals representation.

Contents:

- Analog and digital signal conversion.
- Continuous and discrete signal processing.
- Linear and nonlinear systems.
- Common signal decompositions.
- Convolution – its principle and impulse response.
- Common impulse responses, convolution properties, correlation.
- Fourier transform properties: applications of Fourier transform - spectral analysis of signals, frequency response of systems.
- Discrete Fourier transform. Fast Fourier transform.
- Introduction to digital filters. Moving average filters. Windowed-sinc filters. De-convolution and optimal filters. Recursive filters. The z-transform and Chebyshev filters. Audio and image processing.
- Random signals: summary on random variables: cumulative distribution, probability density function, joint and marginal distributions;
- Random signal characterization; basic properties: stationarity, ergodicity, broad-sense stationarity;
- Basic signals: definition and validity domain;
- Time analysis (correlation) and spectral analysis (power spectral density) of stationary signals;
- Fourier analysis, Wiener-Khintchine theorem;

Assessment: 30% continuous assessment, 70% final exam

Recommended texts and further readings:

- Steven W. Smith, The Scientist and Engineer's Guide to Digital Signal Processing. Second Edition, California Technical Publishing, San Diego, CA, 1999, on-line: www.dspguide.com.
- A.V. Oppenheim, R.W. Schafer, J.R. Buc, Discrete-Time Signal Processing. Second Edition. Prentice-Hall 1999.
- Further readings will be provided by lecturer.

Real-time Systems

Credits: 5	Fall Semester	Compulsory: Yes	
Format	Lectures: 30h	Lab: 30h	Guided project: 15h
Lecturer: Tomasz KRUK			

Objectives:

By attending the course, the student will learn how to deal with issues concerning real-time applications and real-time operative systems, real-time design and programming, embedded systems.

Contents:

Real-time operating systems

- Basic principles;
- Real-time scheduling algorithms for periodic tasks: Rate Monotonic, arliest;
- Deadline First, Deadline Monotonic;
- Real-time scheduling algorithms for aperiodic tasks: scheduling in background;
- Polling Server, Deferrable Server;
- Protocols for accessing shared resources: Priority Inheritance, Priority Ceiling.

Soft real-time systems

- Real-time programming in Posix;
- Thread, mutex and conditional variables;
- Rate Monotonic on Posix Linux;
- Periodic servers;
- Interprocess communication for real-time systems.

Hard real-time systems

- QnX, VxWorks, Windows CE;
- RTAI: periodic and aperiodic tasks; communication mechanisms.

Fundamentals of real-time programming for embedded systems

- General overview of existing families of micro-controllers, DSPs, FPGAs, ASICs;
- Basics of development for embedded systems: coding, compiling, linking, downloading, executing;
- Different kinds of memory devices and memory organization; basic I/O operations; Buses and communication channels;
- Interrupt-driven programming.

Assessment: 30% continuous assessment, 70% final exam

Recommended texts and further readings:

- Giorgio C. Buttazzo, Hard Real-time Computing Systems, Kluwer Academic publishers, 1997.
- Q. Li, C. Yao. Real-Time Concepts for Embedded Systems. CMP Books, 2003.

Modelling and Control of Manipulators			
Credits: 6 **Fall Semester** **Compulsory: Yes**			
Format	Lectures: 30 h	Tutorials: 30 h	
Lecturer: Cezary ZIELINSKI and Piotr TATJEWSKI			

Objectives:

This course presents the fundamentals of the modelling and control techniques of serial manipulators. Topics include robot architectures, geometric modelling, kinematic models, dynamic modelling and its applications, as well as the classical PID controller and computed torques controller.

Contents:

The following subjects will be treated:

- Robot architectures, joint space, operational space,
- Homogenous transformation matrices,
- Description of manipulator kinematics using modified Denavit and Hartenberg notations,
- Direct geometric model,
- Inverse geometric models using Paul's method, Piper's method and general methods,
- Calculation of kinematic Jacobian matrix,
- Inverse kinematics for regular and redundant robots,
- Dynamic modelling using the Lagrange formalism,
- Dynamic modelling using recursive Newton-Euler method,
- Trajectory generation between two points in the joint space and in the operational space,
- Classical PID control
- Computed torque Control.

Assessment: 20% continuous assessment, 80% from end of semester examination.

Recommended texts and further readings:

- W. Khalil, and E. Dombre, Modelling, identification and control of robots, Hermes Penton, London, 2002.
- C.Canudas, B. Siciliano, G.Bastin (editors), Theory of Robot Control, Springer-Verlag, 1996.
- J. Angeles, Fundamentals of Robotic Mechanical Systems, Springer-Verlag, New York, 2002.

Computer Vision			
Credits: 5 **Fall Semester** **Compulsory: Yes**			
Format	Lectures: 30h	Tutorials/examples: 15h	
Lecturer: Wlodzimierz KRASPRZAK			

Objectives:

This course presents the fundamentals in computer vision. Topics include camera modelling, camera calibration, image processing, pose estimation, multi view geometry, visual tracking, and vision-based calibration.

Contents:

- Image formation and auto-calibration.
- Low-level image processing: image normalization, colour spaces, image compression and image filtering.
- Image segmentation: edge detection, chain and line segment detection, Hough transforms, homogeneous region-, shape- and texture description.

- Object classification: the potential functions-, Bayes-, k-NN, SVM- and MLP- classifiers.
- Object recognition: dynamic programming, hypothesis generation-and-test, model-to-image matching and graph search.
- Image motion estimation: gradient- and block-based optical flow, discrete feature motion and active contour tracking.
- Camera technology and vision sensor, Camera model (pinhole, omnidirectional, fisheye, …), Visual geometry, Pose estimation (DeMenthon, Lowe…), Multi view geometry (homography, epipolar geometry, …), Visual tracking, calibration (camera, robots…), Computer vision applications, Computer vision tools.

Assessment: 30% continuous assessment, 70% final exam

Recommended texts and further readings:

- Pitas, Digital Image Processing Algorithms, Prentice Hall, New York, 1993.
- O. Faugeras, Three-dimensional computer vision. A geometric viewpoint, The MIT Press. Cambridge, Mass. 1993, ISBN: 0262061589
- Richard Hartley, Andrew Zisserman, Multiple View Geometry in Computer Vision, Barnes&Nobles, 2nd edition 2004, ISBN-10: 0521540518
- Quang-Tuan Luong, Olivier Faugeras, The Geometry of Multiple Images- The Laws That Govern the Formation of Multiple Images of a Scene, MIT Press, March 2001, ISBN: 0-262-06220-8
- T S Huang, Multiple Calibration and Orientation of Cameras in Computer Vision, Springer, 2001, ISBN: 3 540 65283 3
- Yi MA, Stefano Soatto, Jana Kosecka, S. Shankar Sastry, An invitation to 3D vision: from images to geometric models, Springer, 2004, ISBN 978-0-387-00893-6
- Gari Bradski, Adfrian Kaebler, Learning OpenCV: Computer vision with openCV library, O'Reilly Media, 2008, ISBN: 978-0-596-51613-0

Neural Networks			
Credits: 5	**Fall Semester**	**Compulsory: Yes**	
Format	Lectures: 30h	Tutorials: 15h	

Lecturer: Andrzej KORDECKI

Objectives:

The goal of the class is to present neural networks as tools for pattern classification, function approximation, and system modelling and prediction. Neural methodology will be thus treated as a step-in development of dynamic systems. Neural networks are presented as static or dynamic systems whose main distinctive properties are modularity and adaptability. They are presented in the context of classification, function approximation, dynamical system modelling, and other applications.

Contents:

Classification abilities are discussed for contemporary versions of Rosenblatt's perceptron, support vector machines, and multi-layer perceptrons. They are complemented with elements of learning theory and probably approximately correct estimators. Approximation properties of neural networks are outlined for multilayer perceptrons and for radial basis function networks and connected to linear regression models. In particular, approximation quality and generalization problems are discussed. Back-propagation is derived as an effective way to calculate gradients in large systems. Theoretical abilities of function approximation properties of multi-layer perceptrons

and radial basis function networks are also analyzed. Dynamic neural networks are outlined in the context of dynamical system modelling, contents-addressable memories, and combinatorial system optimization. Neural ARMA models will be derived as a generalization of ARMA models, and their properties will be analyzed. Stability of dynamic networks is discussed in the context of system optimization and contents-addressable memories.
Assessment: 30% continuous assessment, 70% final exam
Recommended texts and further readings: • C.Bekey, K.Y.Goldberg, Neural Networks in Robotics, Kluwer 1993. • Callan, The Essence of Neural Networks, Pearson Education (Academic), 1998.

Mechanical Design Methods in Robotics			
Credits: 5 Spring Semester Compulsory: Yes			
Format	Lectures: 15h	Project: 15 h	Tutorials: 15h
Lecturer: Krzysztof MIANOWSKI			
Objectives: This course presents the overview of the design process – specification, conceptual design, product design. The students will learn basic principles of industrial robot design. **Contents:** The following subjects will be discussed: • Conceptual design: concept generation, concept evaluation. • Product design: documentation, product generation, evaluation for function and performance, evaluation for cost, ease of assembly and other measures. • Computer aids for mechanical design. CAD/CAE/CAM systems. • The design of robotic production cell. • Fundamentals of integrated design of control and drive systems taking into account measurement, gearing and transmission systems. • Design of a serial robot manipulator (using CAD).			
Assessment: 30% continuous assessment, 70% final exam			
Recommended texts and further readings: • K.C.Gupta, Mechanics and Control of Robots, Springer 1997 • J.E.Shigley, J.J.Uicker, Theory of Machines and Mechanisms, McGraw Hill 1995. • Further readings: CAD software documentation			
Prerequisites: Modeling and control of manipulators			

Robot Programming Methods			
Credits: 4 Spring Semester Compulsory: Yes			
Format	Lectures: 15h	Tutorials: 15h	
Lecturer: Cezary ZIELINSKI			
Objectives: To learn the robot programming methods. **Contents:**			

Several historic and currently used specialized robot-programming languages will be presented. Then focus will shift to robot programming frameworks, i.e.: libraries of modules, a pattern according to which they have to be assembled and tools for producing new modules. Robot will be treated as an embodied agent and its operation will be described formally in terms of transition functions. Both sequential and concurrent decompositions of those functions will be considered. Competitive and cooperative composition of results and the definition of complex behaviours will be the subject of presentation. The transition from synchronous to event driven systems will be shown. Deliberative vs. behavioural, fuzzy vs. crisp, deterministic vs. indeterministic systems will be described from the point of view of the definition of the transition functions governing their behaviour. Cooperation and coordination in multi-robot systems will be described. The course will also cover implementation issues, especially programming paradigms (procedural, object-oriented, component based). Error handling and debugging issues will also be explained. The presentation of implementation structures (methods of merging specialized languages and programming frameworks and the influence on the compilation/interpretation of the resulting code) will follow. An introduction to formal languages and how to build a simple compiler of a robot language will be shown. MRROC++ robot programming framework will be used for presenting examples of complex systems, e.g. capable of two-handed manipulation with force sensing, visual servoing, voice communication and capability to reason. The course will conclude with the description of software for swarms of autonomous robots and coordinated multi-robot systems requiring utility-based task allocation.
Assessment: 30% continuous assessment, 70% final exam
Recommended texts and further readings: • Zieliński C.: Robot Programming Methods. Warsaw University of Technology Publishing House, 1995. • Zieliński C.: Transition-Function Based Approach to Structuring Robot Control Software. In: Robot Motion and Control: Recent Developments. Ed. • K. Kozłowski, Lecture Notes in Control and Information Sciences, Vol.335, Springer Verlag. 2006.pp 265-286 • Further readings will be provided by lecturer

Mobile Robots			
Credits: 4	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 15h	Tutorials: 15h	
Lecturer: Wojciech SZYNKIEWICZ			
Objectives: This course presents fundamentals of wheeled mobile robots modelling, control and localization. **Contents:** The following subjects will be addressed: • Non holonomic constraint equations, • Classification of robots, using the degrees of mobility and steering, • Posture kinematic model, • Configuration kinematic model, • Motorisation of wheels, • Dynamic models including the contact model,			

• Trajectory generation, • Controllability and stabilisation, static and dynamic feedback linearization, nonlinear control based on Lyapunov, • Relative localisation: odometry, inertial systems. • Absolute localization: GPS, sensor fusion, • 3D range measurements and goniometry, • Analysis of the observability of robot location, • Path planning.
Assessment: 30% continuous assessment, 70% final exam
Recommended texts and further readings: • C.Canudas, B. Siciliano, G.Bastin (editors), Theory of Robot Control, Springer-Verlag, 1996. (chapters 7,8, and 9) • Ch. Ahikencheikh, A. Seireg, Optimized-Motion Planning; Theory and Implementation. John Wiley 1994. • R.Siegwart I.R. Nourbakhsh, Intrduction to Autonomous Mobile Robots, MIT Press second edition 2010. B.Siciliano, O.Khatib,edt , Robots Handbook, Springer-Verlag 2008, Chapters 17, 34, 35.

Artificial Intelligence			
Credits: 4 **Spring Semester** **Compulsory: Yes**			
Format	Lectures: 15h	Tutorials: 15h	
Lecturer: Włodzimierz KASPRZAK			
Objectives: The goal of the course is to present advanced issues of artificial intelligence from the perspective of a computerized autonomous agent. **Contents:** • The first part covers basic methods of artificial intelligence – the logic of knowledge representation, inference rules and problem solving including: uniformed search, informed search with heuristic functions, constraint satisfaction problems and adversarial games. • The second part deals with practical planning and acting of an autonomous agent (i.e., situation space, plan space, plan decomposition, hierarchic decomposition, contingency planning), and with probabilistic reasoning. • The third part discusses agent design problems in the area of knowledge acquisition (learning from observations, in neural networks and reinforcement learning), and machine perception (image and speech understanding).			
Assessment: 30% continuous assessment, 70% final exam			
Recommended texts and further readings: • S. Russell, P. Norvig, Artificial Intelligence: A Modern Approach. Prentice Hall, Upper Saddle River, N.J., 2002. • Stefano Nolfi, Dario Floreano (2000), Evolutionnary robotics, MIT Press. • S. Russell, P. Norvig, Artificial Intelligence: A Modern Approach. Prentice Hall, Upper Saddle River, N.J., 2002.Problem Solving, Addison Wesley, 1997. • G.F. Luger, W.A. Stubblefield, Artificial Intelligence. Structures and Strategies for Complex			

Problem Solving, Addison Wesley, 1997 • J-P. Delahaye, Formal Methods in Artificial Intelligence, Oxford 1987

Embedded Systems			
Credits: 4 **Spring Semester** **Compulsory: Yes**			
Format	Lectures: 30h	Tutorials: 15h	
Lecturer: Visiting Professor from UNIGE			
Objectives: This course presents the fundamentals of embedded systems from both the architectural point of view and the basics of programming, with particular attention to sensing and actuating devices. **Contents:** The following topics are treated: • General overview of existing families of micro-controllers, DSPs, FPGAs, ASICs • Basics of developing for embedded systems: coding, compiling, linking, downloading, executing. • Different kinds of memory devices and memory organization. • On-chip and off-chip peripherals units and basic I/O operations: ADC, DAC, PWM, Parallel port, Counters, Timers. • Buses and communication channels. • Interrupt-driven programming. • Fundamentals of real-time programming for embedded systems.			
Assessment: 30% continuous assessment, 70% final exam			
Recommended texts and further readings: • Q. Li, C. Yao, Real-Time Concepts for Embedded Systems, CMP Books, 2003. (ISBN:1578201241). • D. E. Simon, An Embedded Software Primer, Addison-Wesley Professional, 1999. (ISBN: 020161569X) • A. S. Berger, Embedded Systems Design: An Introduction to Processes, Tools and Techniques, CMP Books, 2001. (ISBN: 1578200733).			

Optimization Techniques			
Credits: 4 **Spring Semester** **Compulsory: Yes**			
Format	Lectures 15 h	Tutorials 15 h	
Lecturer: Włodzimierz OGRYCZAK			
Objectives: The main objective of the course is to introduce its participants to the theory and solution methods for optimization problems in science and technology. The students will be able to: understand various theoretical and computational aspects of a wide range of optimization methods, realize the capabilities offered by various optimization methods, use of optimization toolboxes. **Contents:** • Concepts and models of mathematical programming • Linear programming • Basic concepts and algorithms for (nonlinear) unconstrained			

optimization • Theory of constrained optimization • Algorithms of nonlinear (constrained) programming • Discrete optimization • Multicriteria optimization
Assessment: 40% continuous assessment, 60% final exam (2h)
Recommended texts and further readings: • H.P. Williams, Model Building in Mathematical Programming, 5th Ed, Wiley 2013. • M.S. Bazaraa, J.J. Jarvis, H.D. Sherali, Linear Programming and Network Flows, 4th Ed, Wiley, 2010. • M.S. Bazaraa, H.D. Sherali, C.M. Shetty, Nonlinear Programming, Wiley, 2006. • A.P. Ruszczyński, Nonlinear Optimization, Princeton Univ. Press, 2006. • I.Maros, Computational Techniques of the Simplex Method, Kluwer, 2003. • M.Ehrgott, Multicriteria Optimization, Springer, Berlin 2005. • A.Kasperski, Discrete Optimization and Network Flows, Wroclaw Univ. of Technology, 2011.

Group Project			
Credits: 5	**Spring Semester**	**Compulsory: Yes**	
Format	Lectures: 15h		
Lecturer: Teresa ZIELINSKA and professors at WUT			
Objectives: The aim of this module is to provide students with the opportunity to apply their specialized knowledge to the solution of a real problem and gain practical experience of the processes involved in the team-based design and testing of a robotic system. **Contents:** The course is divided into two parts: • Lectures about project management: These lectures are based on the corpus of knowledge provided by the Project Management Institute; the PMBoK (Project Management Book ok Knowledge) and will comprise some practical works on a project management software. - Introduction to project management (organization, process, …) - Initiating, Planning, Executing, Controlling and closing a project, - Risks evaluation and management: Human and organisational risks, Risks management. - Professional Responsibility • Solution of robotic problem with innovative function or structure. The problem solution should be defined by the group and must make use of advanced sensors and control algorithms.			
Assessment: 100% Course Work, based on the documentation produced at each stage of the process, a presentation and demonstration of the final product, the effectiveness of the team's management of the project, and the understanding and contribution of each individual.			

Recommended texts and further readings: • Recommended texts will be given by the lecturers.
Prerequisites: All compulsory modules from first semester

6. ANNEX 2 : LIST OF THE SECOND YEAR MODULES IN JAPAN

2019 Course List for International Graduate Programs (April 2019 - March 2020)

Program	Code	Subject	Sem.	Cr.	Time	Room	Professor
General Course	09927	SCIENCE,TECHNOLOGY AND CULTURE	Fall	2	Thu/2	12-102	IMOTO, YUKI
	09286	TECHNICAL COMMUNICATION 1	Spring	2	Fri/2	12-106	IMOTO, YUKI
	09267	TECHNICAL COMMUNICATION 1			Thu/2	12-101	DIL, JONATHAN
	09305	TECHNICAL COMMUNICATION 2	Fall	2	Fri/2	12-106	IMOTO, YUKI
	02980	TECHNICAL COMMUNICATION 2			Thu/2	12-101	DIL, JONATHAN
	10267	MACROECONOMIC DEVELOPMENTS AND ECONOMIC POLICY IN JAPAN	Fall	2	Wed/2	11-13	SAITO, JUN
Fundamental Science and Technology	00748 00805	INTERNSHIP	Spring Fall	2			HOSHINO, KAZUO
	12403	CHEMISTRY AND DAILY LIFE	Fall	2			Not offered in 2019
	12365	PRACTICAL PRESENTATION IN CHEMISTRY 1	Spring	2			Not offered in 2019
	12370	PRACTICAL PRESENTATION IN CHEMISTRY 2	Fall	2			Not offered in 2019
	12331	TOPICS IN CARBOHYDRATE CHEMISTRY	Spring	2			Not offered in 2019
	12384	SEMINAR ON MODERN ORGANIC CHEMISTRY 1	Spring	2			Not offered in 2019
	12399	SEMINAR ON MODERN ORGANIC CHEMISTRY 2	Fall	2			Not offered in 2019
	12346	TOPICS IN ORGANOCATALYSIS	Fall	2			Not offered in 2019
	08089	ANALYTICAL METHODS IN APPLIED PHYSICS AND INFORMATICS	Spring	2	Mon/2	12-102	HONDA, SATOSHI
	00312	SUPERCONDUCTIVITY AND SOLID STATE ENGINEERING	Spring Q2*1	2	Mon/4, 5	12-208	KAMIHARA, YOICHI
	12150	PHYSICS AND MODELING OF SEMICONDUCTOR DEVICES	Fall	2			Not offered in 2019
	00590	QUANTUM ELECTRONICS	Fall	2	Thu/2	12-103	HAYASE, JUNKO
	00418	MATHEMATICAL ENGINEERING FOR QUANTUM MECHANICS	Spring	2	Thu/4	14-202	YAMAMOTO, NAOKI
	08093	NATURAL PRODUCTS CHEMISTRY	Fall	2			Not offered in 2019
	11077	CONTROL THEORY FOR BIOSYSTEM	Fall	2			Not offered in 2019
	02133	SYSTEM BIOMECHANICS	Spring	2			Not offered in 2019
	02148	INTELLIGENT MACHINE SYSTEM	Fall Q1*1	2	Mon/1, 2	12-101	MURAKAMI, TOSHIYUKI
	02152	INFORMATION OPTICS AND OPTICAL MEASUREMENTS	Spring	2	Tue/3	12-102	OKADA, EIJI
	09142	OPTICAL FUNCTIONAL MATERIALS	Spring	2	Tue/3	14-201	KOIKE, YASUHIRO
	09931	NON-LINEAR DYNAMICS IN CHEMICAL SYSTEM	Spring	2	Tue/1	12-206	ASAKURA, KOICHI
Integrated Design Engineering	00752 00810	INTERNSHIP	Spring Fall	2			AOYAMA, HIDEKI
	08390	SPECIAL TOPICS ON ENGINEERING FOR SYNTHESIS AND DESIGN B	Fall	2	Tue/2	12-105	KIM, YUNJAE
	00111	SPACE EXPLORATION ENGINEERING	Fall	2	Fri/2	14-201	ISHIGAMI, GENYA
	02391	ULTRAPRECISION MACHINING AND METROLOGY	Spring	2	Mon/2	12-202A	YAN, JIWANG
	07082	MATHEMATICAL AND PHYSICAL METHODS IN FLUID DYNAMICS	Fall	2	Thu/1	12-209	SAWADA, TATSUO
	01228	BIOMIMETIC MICRO/NANO ENGINEERING	Spring	2	Mon/3	12-109	ONOE, HIROAKI
	01945	MECHANICAL INTERFACE DESIGN	Fall	2	Thu/3	12-106	MORITA, TOSHIO
	02406	MEMS: DESIGN AND FABRICATION	Spring	2	Thu/2	12-105	MIKI, NORIHISA
	08165	ADVANCED DESIGN AND PRODUCTION SYSTEM	Spring	2	Mon/3	12-102	AOYAMA, HIDEKI OYA, TETSUO
	12035	ADVANCED CONTROL SYSTEMS DESIGN	Spring	2	Mon/2	12-105	OHMORI, HIROMITSU NAMERIKAWA, TORU
	08036	SYSTEM BIOMECHANICS	Spring	2			Not offered in 2019
	08170	INTELLIGENT MACHINE SYSTEM	Fall Q1*1	2	Mon/1, 2	12-101	MURAKAMI, TOSHIYUKI
	00145	ADVANCED SYSTEM ELECTRONICS	Fall	2			Not offered in 2019
	00126	ADVANCED SIGNAL PROCESSING	Spring	2	Wed/1	12-106	YUKAWA, MASAHIRO
	07264	DIGITAL WIRELESS COMMUNICATIONS	Spring	2	Mon/2	14-211	SANADA, YUKITOSHI
	12054	COMPREHENSIVE EXERCISE OF ELECTRONICS AND ELECTRICAL ENGINEERING	Spring	2	Mon/4	11-31	TANABE, TAKASUMI
	12164	PHYSICS AND MODELING OF SEMICONDUCTOR DEVICES	Fall	2			Not offered in 2019
	08222	OPTO-ELECTRONICS	Spring	2	Thu/1	12-208	KANNARI, FUMIHIKO
	08237	INFORMATION OPTICS AND OPTICAL MEASUREMENTS	Spring	2	Tue/3	12-102	OKADA, EIJI
	10453	OPTICAL CONTROL OF QUANTUM SYSTEMS	Spring	2			Not offered in 2019
	10085	OPTICAL NETWORK SYSTEM	Fall	2	Fri/2	12-102	TSUDA, HIROYUKI
	08438	PHOTONIC NANOSTRUCTURE	Spring	2	Tue/5	12-207	TANABE, TAKASUMI
	12073	ORGANIC ELECTRONIC MATERIALS AND DEVICES	Spring	2	Fri/1	12-211	NODA, KEI
	12069	LASER PROCESSING	Fall	2	Mon/3	11-16	TERAKAWA, MITSUHIRO
	12092	CHEMICAL SENSORS / BIOSENSORS AND SENSING MATERIALS	Spring	2	Tue/2	12-206	CITTERIO, DANIEL
	03751	FUNCTIONAL THIN FILM ENGINEERING	Spring	2	Thu/2	14-202	SHIRATORI, SEIMEI
	07977	TECHNICAL ENGLISH FOR INTEGRATED DESIGN AND ENGINEERING	Spring	2			Not offered in 2019
	08199	OPTICAL FUNCTIONAL MATERIALS	Spring	2	Tue/3	14-201	KOIKE, YASUHIRO
	09946	NON-LINEAR DYNAMICS IN CHEMICAL SYSTEM	Spring	2	Tue/1	12-206	ASAKURA, KOICHI
	09104	INTRODUCTION TO COMPUTATIONAL SOLID MECHANICS	Spring Q1*1	2	Mon/2 Thu/3	12-207	OGUNI, KENJI
	08639	COMPUTER ARCHITECTURE	Spring	2	Thu/1	12-204	AMANO, HIDEHARU
	08901	COMPUTER VISION	Spring	2	Mon/5	14-202	SAITO, HIDEO
Science for Open and Environmental Systems	00786 00441	INTERNSHIP	Spring Fall	2			TAKADA, SHINGO
	09119	INTRODUCTION TO COMPUTATIONAL SOLID MECHANICS	Spring Q1*1	2	Mon/2 Thu/3	12-207	OGUNI, KENJI
	00255	ANALYSIS OF ARCHITECTURAL FORM	Fall	2	Fri/5	34-321	ALMAZAN CABALLERO, JORGE
	01763	ARCHITECTURAL AND BUILDING DESIGN STUDIO B	Spring	4			Not offered in 2019
	00657	DYNAMICS IN ARCHITECTURAL ENGINEERING	Spring	2			Not offered in 2019
	08017	PUBLIC SPACE AND COMMUNICATION	Fall	2	Wed/2	12-106	INOUE, KYOKO
	01649	ADVANCED COURSE ON SUSTAINABLE ARCHITECTURE AND CITIES	Fall	2			Not offered in 2019

Program	Code	Subject	Sem.	Cr.	Time	Room	Professor
Science for Open and Environmental Systems	**08533**	THERMAL AND REACTIVE FLUID DYNAMICS	Spring	2	Fri/1	12-209	UEDA, TOSHIHISA
	00150	NON-LINEAR DYNAMICS IN CHEMICAL SYSTEM	Spring	2	Tue/1	12-206	ASAKURA, KOICHI
	01979	ADVANCED ACTUATOR ENGINEERING	Fall	2			Not offered in 2019
	10032	COMPRESSIBLE FLUID DYNAMICS	Spring	2	Mon/2 Wed/1 *2	12-102	MATSUO, AKIKO
	00661	ADVANCED COURSE IN APPLIED AND COMPUTATIONAL MECHANICS 2	Fall	2	Mon/1	14-202	OGIHARA, NAOMICHI OBI, SHINNOSUKE TAKANO, NAOKI MATSUO, AKIKO YASUOKA, KENJI FUKAGATA, KOJI MURAMATSU, MAYU
	00700	FUNDAMENTALS OF MULTIPHASE FLOW	Spring	2	Mon/4	12-207	ANDO, KEITA
	01983	BIOMECHANICS AND CONTROL OF HUMAN MOVEMENTS	Fall	2			Not offered in 2019
	09965	ADVANCED COURSE OF MOLECULAR DYNAMICS	Fall	2	Thu/2	12-209	YASUOKA, KENJI
	10066	FINITE ELEMENT MODELING AND SIMULATION	Fall	2	Tue/1	12-206	MURAMATSU, MAYU TAKANO, NAOKI
	13357	MECHANICS AND NUMERICAL SIMULATION OF ADVANCED MATERIALS	Spring	2	Tue/2	11-21	TAKANO, NAOKI MURAMATSU, MAYU
	02444	FUNDAMENTALS OF TURBULENCE AND ITS THEORY	Spring	2	Fri/2	12-206	FUKAGATA, KOJI
	02239	INTRODUCTION TO TURBULENCE MODEL AND ITS APPLICATION	Fall	2	Tue/5	12-209	OBI, SHINNOSUKE
	02937	AD HOC AND SENSOR NETWORK	Fall	2	Mon/3	14-201	OTSUKI, TOMOAKI
	03311	ADVANCED COURSE OF INTERNET BACKBONE ARCHITECTURE	Spring	2	Mon/2	14-204	YAMANAKA, NAOAKI
	08878	TOPICS IN COMPUTER OPERATING SYSTEMS	Spring	2	Tue/3	14-203	KONO, KENJI
	08830	FORMAL PROGRAMMING LANGUAGE THEORY	Spring	2	Mon/3	14-B101	TAKIMOTO, MUNEHIRO
	08624	COMPUTER ARCHITECTURE	Spring	2	Thu/1	12-204	AMANO, HIDEHARU
	02057	ADVANCED COURSE ON COMPUTER VISUALIZATION	Spring	2	Thu/4	14-201	FUJISHIRO, ISSEI
	00714	COMPUTER SCIENCE: EXERCISES	Fall	2	*3		TAKADA, SHINGO
	07408	COMPUTER VISION	Spring	2	Mon/5	14-202	SAITO, HIDEO
	02922	SYSTEMS PERFORMANCE EVALUATION	Fall	2			Not offered in 2019
	08863	ADVANCED COURSE ON NATURAL LANGUAGE PROCESSING	Fall	2	Fri/4	12-102	SAITO, HIROAKI
	03675	DESIGN OF PHYSICALLY GROUNDED COMMUNICATION SYSTEM	Spring	2	Fri/2	12-101	IMAI, MICHITA
	12202	SOFTWARE ENGINEERING: DEVELOPMENT AND TESTING	Spring	2	Tue/5	12-101	TAKADA, SHINGO
	08548	ADVANCED COURSE ON DIGITAL COMMUNICATION THEORY	Spring	2	Tue/2	14-204	SASASE, IWAO
	09252	ADVANCED COURSE IN DATABASE SYSTEMS	Spring	2	Fri/3	12-104	TOYAMA, MOTOMICHI
	03326	ADVANCED COURSE ON NETWORK ENGINEERING	Fall	2	Mon/4	12-106	TERAOKA, FUMIO
	00729	ADVANCED COURSE ON NETWORK SERVICES	Fall	2	Fri/2	12-105	KANEKO, KUNITAKE
	00733	MIXED REALITY	Spring	2			Not offered in 2019
	09200	DISTRIBUTED SYSTEMS	Fall	2	Fri/5	12-103	MATSUTANI, HIROKI
	12126	MODELS FOR CONCURRENCY	Spring	2	*4	12-207	YOSHIDA, NOBUKO
	02540	MICROPROCESSOR ARCHITECTURE	Fall	2	Thu/3	12-103	YAMASAKI, NOBUYUKI
	12145	ADVANCED COURSE ON APPLICATION OF EXPERIMENTAL DESIGN	Fall	2			Not offered in 2019
	08571	APPLIED STATISTICAL ANALYSIS	Fall	2	Mon/2	12-209	SUZUKI, HIDEO
	02076	OPEN SYSTEMS MANAGEMENT: LECTURE AND EXERCISES	Fall	2	Thu/4,5	14-211	IMAI, JUNICHI SUZUKI, HIDEO HIBIKI, NORIO MASUDA,YASUSHI MATSUKAWA, HIROAKI YAMAGUCHI, TAKAHIRA YAMADA, SHU MATSUURA, SHUN KURIHARA, SATOSHI
	02061	OPERATIONS MANAGEMENT	Spring	2	Mon/2	14-203	MATSUKAWA, HIROAKI
	09123	MODELING AND ANALYSIS OF STOCHASTIC SYSTEMS	Fall	2	Fri/4	14-204	MASUDA, YASUSHI
	13361	ADVANCED COURSE ON TOTAL QUALITY MANAGEMENT	Fall	2	Fri/5	12-101	YAMADA, SHU
	01801	ADVANCED FINANCIAL ENGINEERING I	Spring	2	Tue/3	12-202C	IMAI, JUNICHI
Japanese	**05682**	JAPANESE 1A	Fall	1	Please see the Japanese Class Schedule for the latest information		
	03015	JAPANESE 1B	Fall	1			
	03053	JAPANESE 1C	Spring	1			
	03201	JAPANESE 1D	Spring	1			
	03216	JAPANESE 2A	Fall	1			
	05697	JAPANESE 2B	Spring	1			
	05754	JAPANESE 3A	Fall	1			
	03350	JAPANESE 3B	Spring	1			
	05769	JAPANESE 4A	Fall	1			
	03292	JAPANESE 4B	Spring	1			
	00949	JAPANESE ELEMENTARY CONVERSATION	Fall	1			
	00604	JAPANESE ELEMENTARY CONVERSATION 2	Fall	1			

*1 Most courses are taught on a semester system, but the courses marked "Q1" or "Q2" are conducted on a quarter system which divides a semester into two halves.
Spring Q1courses: April to May
Spring Q2 courses: first class day of the courses are as follows: Monday June 10, Tuesday June 4, Wednesday June 5, Thursday June 6, Friday June 7, Saturday June 8
Fall Q1 courses: September to mid-November
Fall Q2: first class day of the courses are as follows: Monday November 18, Tuesday Nov 26, Wednesday Nov 20, Thursday Nov 28, Friday Nov 15, Saturday Nov 16
Please confirm page 4-7 of the "Course Guidebook and Syllabus" for class schedule.

*2 "COMPRESSIBLE FLUID DYNAMICS": Lecture days are as follows: April 8, 10, 15, 17, 22, 24 May 6, 8, 13, 15, 20, 22 June 5 and 10

*3 "COMPUTER SCIENCE: EXERCISES": This course does not have lectures.

*4 "MODELS FOR CONCURRENCY": This is an intensive course. Lecture days are as follows: August 5 and 6 period 1 - 5, August 7 period 1 - 4